MF-I62

1st Asia-Pacific Conference on Plasma Physics, 18-22, 09.2017, Chengdu, China

Using Integrated Data Analysis to optimize measurements critical to the validation of MHD simulations

M.D. Nornberg[1], D.J. Den Hartog[1], L. Reusch[1], and the MST team
[1] University of Wisconsin-Madison, USA

More and more, our understanding of magnetically confined plasmas is advanced by what we learn from numerical simulations of fusion-grade plasmas. The reliability of these simulations depends on the accuracy of the model used to describe the underlying plasma processes. Great effort is being made to validate these predictions with reliable and accurate experimental data. Diagnostic information from magnetic confinement fusion experiments will become sparser, however, as devices enter the regime of burning plasmas. Executing measurements of sufficient precision and accuracy to provide an adequate quantitative description of plasma properties is always difficult; they are limited in scope, scale, and resolution. There are often underlying systematic uncertainties which are harder to detect and correct than statistical uncertainties. And some plasma properties are difficult to determine from individual diagnostics.

In this talk, we will see how Integrated Data Analysis (IDA) provides a systematic method to address these challenges to help advance the validation effort. IDA aids in optimizing the information extracted from a heterogeneous, complementary set of diagnostics. The goal is to create a single probabilistic analysis framework that transparently and reliably incorporates all of the plasma parameter dependencies between diagnostics. When two or more diagnostics share some dependency, the framework ensures that results are consistent over all the diagnostic data. This consistency makes the analysis sensitive to previously unidentified systematic uncertainties, including both instrument calibration and diagnostic model assumptions.

In IDA, we employ a Bayesian probability methodology to make inferences from both prior knowledge and acquired data. The modularity of the method provides a natural means of determining how inferences are changed when introducing new diagnostic information. The need to specify a prior probability distribution ensures that our descriptions of the working model inherently enumerate and quantify our assumptions. These methods differ from standard analysis techniques that tend to simplify the model for a single diagnostic that often avoid incorporating information that is difficult to quantify. IDA exploits the redundant dependencies of complementary diagnostics to help resolve data inconsistencies that arise in standard analysis techniques.

One example of a successful implementation of IDA is the quantification of the plasma effective charge Z_{eff} in enhanced confinement plasmas in the Madison Symmetric Torus (MST). Quantifying Z_{eff} is critical to determining the plasma collisional resistivity, Ohmic heating, and radiative losses, yet there are relatively few reliable techniques for measuring it. Previous attempts at using bremsstrahlung emission were thwarted by the dominance of other sources of continuum emission. We can quantify the density of individual impurity species using charge exchange recombination spectroscopy (CHERS), though there is always the possibility of contributions from additional unmeasured species.

When we applied the IDA methodology to incorporate CHERS impurity density measurements with SXR tomography, we were able to resolve several issues, the first of which is the appropriate description of SXR emission. SXR emission in MST is dominated by impurity recombination so the model requires a quantitative description of the impurity density profiles. The profiles were constrained by CHERS core and mid-radius measurements and the modeled emission provided very good agreement with the SXR measurements. We were then able to calculate not only the profile of Z_{eff}, but also infer how much Z_{eff} would change if other impurities were included in the model for which we had no CHERS data.

The inferred quantitative description of the effective charge in these plasmas is critical to our ongoing work in validating the resistive MHD description of magnetically-confined plasmas. Specifically, we are using results obtained with IDA to aid in the effort to validate the scaling of magnetic turbulence with Lundquist number in MHD simulations using the DEBS and NIMROD codes. Such techniques are also very valuable as we start to study burning plasmas in which the nuclear environment necessitates a sparser diagnostic set.

References

M.E. Galante, *et al.*, Determination of Zeff by integrating measurements from x-ray tomography and charge exchange recombination spectroscopy, Nucl. Fusion **55**, 123016 (2015).

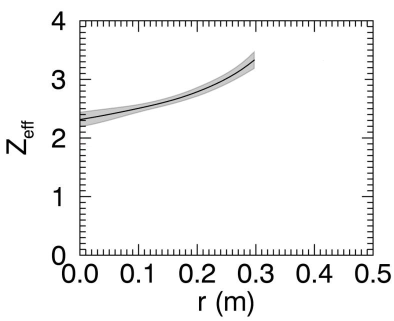

Figure 1: Z_{eff} profile determined by integration of SXR tomography and CHERS impurity measurements.